Application Note

Discussion on Probe Tip and Device Temperatures when Operating the VectorStar ME7838A Broadband System

The VectorStar ME7838A Broadband system operates from 70 kHz to 110 (125) GHz utilizing the small, compact 3743x mmWave module. The ME7838A system offers on-wafer device characterization with significantly improved performance and convenient installation. With the advent of the new ME7838A has come the possibility of broadband on-wafer measurements with increased dynamic range and dramatically enhanced measurement stability (thus providing longer measurement time between calibrations). These performance enhancements have also been achieved in a package that is 1/50th of the volume of previous mmWave extension modules.

Since the surface temperature of the 3743X mmWave modules can be above room temperature, the question arises if the temperature of the device under test can be affected (and by how much) and could the calibration be affected? Because of the high thermal resistance to the connector, to the probe tip and the even higher thermal resistance to the substrate, the temperature changes (when system properly installed) are near 0 (within the repeatability limit) and data on this subject will be presented. Since the absolute temperature changes are so small, the calibration question becomes ancillary but it may be interesting to look at the effect of calibration standard temperature on the calibration quality over a wider range. Data will be presented that indicates that over at least 15 °C swings, there are no detectable variations in calibration residuals using standard components.

This paper explains the methodology and the results supporting the above conclusions for both a cable-connected module and a direct-connect module.

Broadband System Configuration

Previous installations using the old style, bulky mmWave modules include the use of long (~6”) 1mm cables between the module test port and the probe. Long cables are used due to the difficulty locating large mmWave modules close to the probes on a wafer probe station platen. The result of using long 1mm test port cables is a dramatic reduction in dynamic range, raw directivity, and measurement stability. As an alternative, the compact size of the 3743x mmWave modules provide the opportunity to significantly reduce, or eliminate completely, the test port cables for maximum performance.

If the choice is made to include a 1mm cable between the 3743x module and probe, the compact size means the module can now be mounted much closer to the probe. The result is a 1mm cable as short as 3” (instead of the typical 6”) can be used and thereby reduce performance degradation due to cable loss by half. Thus the superior performance differential of the 3743x mmWave module compared to previous mmwave modules is maintained and even improved. An additional result of using a 1mm cable is thermal isolation. The 3” 1mm cable provides complete thermal isolation between the 3743x mmWave module and probe test port. There will therefore be no rise in temperature at the probe tip when using a 1mm cable between the module and probe if that is a goal.

However, many users will want to take advantage of the possibility to improve performance even further by connecting these compact mmWave modules directly to the probe. By doing so and removing the losses associated with the cable, both dynamic range and stability are further enhanced as compared to the larger systems on the market. Using the direct connect method results in a small rise in probe tip temperature, however, further measurements show this to cause minimal impact on actual measurement results.

Temperature change at the probe tip

With the 3743X modules mounted in a probe station with Cascade Infinity probes, the probes were landed on a modified alumina calibration substrate with a thermocouple attached to the substrate about 100 µm away from the landing pads. The physical arrangement is shown schematically in Fig. 1. The thermocouple was soldered to a metal pad on the substrate to ensure its thermal conduction. The accuracy of the thermocouple assembly was verified by placing the thermocouple-mounted-substrate in a calibrated thermal chamber.

The system was turned on and the temperature evolution monitored over the period of an hour (the module case temperature stabilized to within 0.5 °C within 40 minutes in this case). The temperature plot is shown in Fig. 2 for the case of the 3-inch W1 cables connecting the module and the probe. In this case, there was no detectable change on the probe.

This experiment was repeated for the case of the direct-probe-connect. This setup does offer slightly better dynamic range and raw directivity since the cable loss is removed (approximately 0.7 dB at 60 GHz and 1.2 dB at 110 GHz). Cables of this type have historically been used with other systems but can be avoided with the direct connect approach. The temperature results in this case are plotted in Fig. 3. Because of the tighter integration there is a minor amount of heat transmission (again limited by the thermal resistance of the interconnect and of the probe itself). The maximum rise was 2.7 °C.

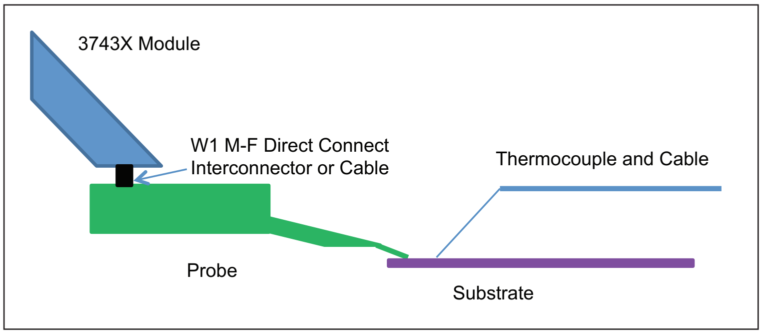

Figure 1. The arrangement for the temperature measurement is shown here. The mounting arms are not shown for clarity.

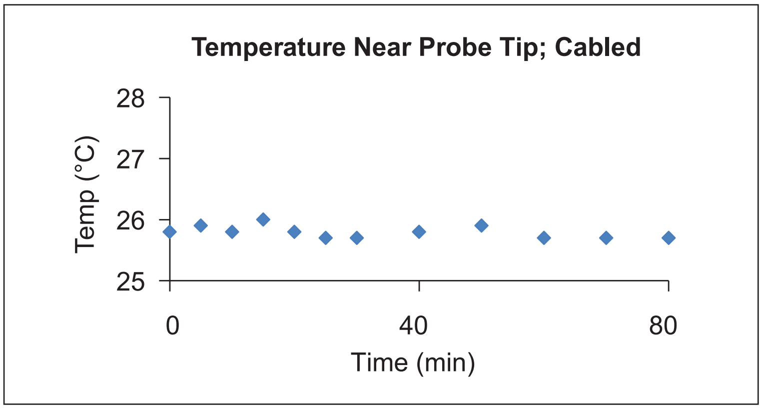

Figure 2. Probe temperature as a function of time after system turn-on is shown here for the case of the cabled module (3”). The variation is less than the repeatability of the temperature measurement.

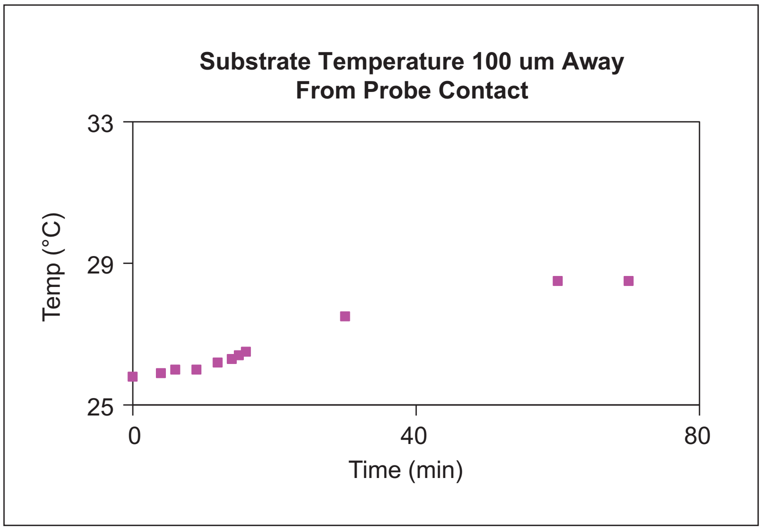

Figure 3. The temperature measured on the substrate using the setup of Fig. 1(direct connect version) as a function of time after turn-on is shown here.

Calibration variation

While the temperature variations shown above range from small to non-existent, a reasonable question is what temperature variation is required for the performance of typical calibration standards (and hence the quality of the calibration itself) to be affected. To answer this question, a series of calibrations were conducted (OSL and SSS calibrations merged) where the system was kept at normal operating temperature but the standards themselves were heated. The calibration kit coefficients were not changed so this is, in effect, seeing if the parameter change of the components themselves is enough to cause a measurable effect on the calibration. The temperature changes studied were very large (much larger than an instrument would generate) to study the calibration components in more detail. These experiments were done coaxially but we will comment on the on-wafer aspects later.

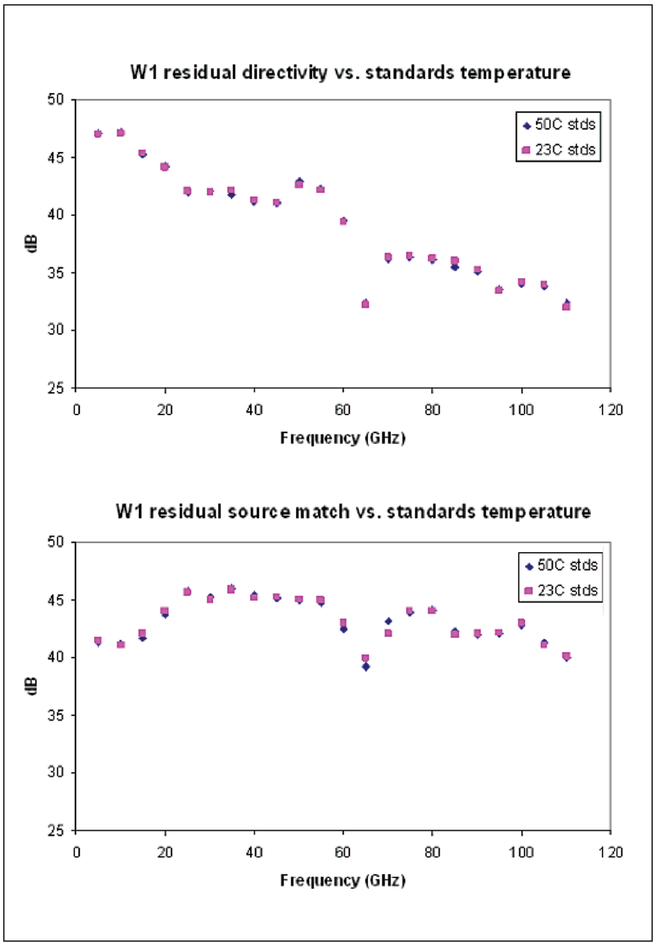

Figure 4. The calibration residuals when the calibration standards were at wildly different temperatures are plotted here. The scatter is within the repeatability limit.

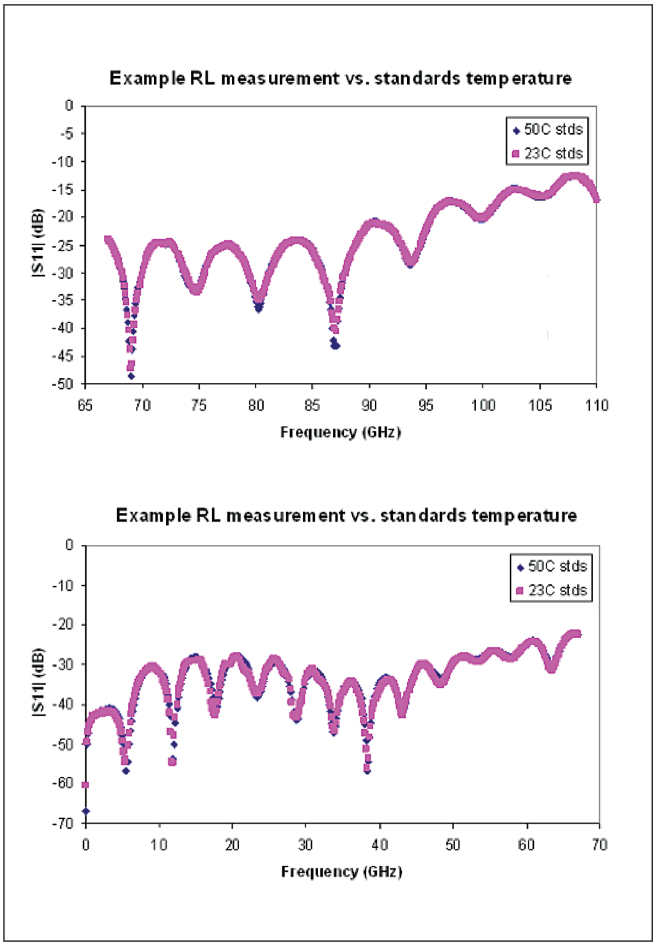

Figure 5. Two return loss measurements are shown here based on the calibrations performed using standards at wildly different temperatures

The primary mode of evaluation was to study the calibration residuals which were measured with a 1 mm airline and either a short (for residual source match) or an offset termination (15 dB return loss, for residual directivity). The resulting ripple patterns in reflection were used to extract the residual parameters. In this case, we will compare the results when the standards were at ambient (23 °C in this case) or when they were heated to 50 °C immediately before the calibration. Since each calibration step took under 10 seconds, it is not believed that the standards cooled much during that step execution. The residuals for this case are plotted in Fig. 4. The scatter that was observed in the data is within the repeatability limits of the measurement.

As a more practical test of this, two return loss measurements were conducted using the calibrations discussed above. These results are shown in Fig. 5. The scatter is well within the repeatability limit of the measurement (note the agreement even in the deeper nulls).

From this, it is believed safe to conclude that the calibration based on OSL and SSS standards is invariant to standards temperature spanning from 23 to 50 °C at least. It is believed that a similar behavior would apply to on-wafer calibrations assuming the temperature coefficients (primarily of the load standards) are not significantly worse. Unless the substrate is of an unusual material, it is expected that TRL calibrations would be less sensitive.

Conclusions

Measurement data indicates that the temperature rise at the DUT plane in an on-wafer measurement due to instrument heating ranges from small to non-existent when using the ME7838A system (or its derivatives) depending on the mounting scheme. In terms of calibrations alone, vast temperature changes on the standards (at least for the coaxial case) can be tolerated before the residuals or the measurement results are altered.

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